

Beyond Our Solar System: Our Search for Planets

An Honors Thesis (HONR 499)

by

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Abstract

Planetariums act as windows of scientific information; they have enabled the human race to study the stars in the daytime, and to share that knowledge with the public. Over the years, planetarium shows have changed as technology has advanced, moving from a simple pinhole replication of the night sky, to a hybrid system of lenses, LED lights, and dual projection. But when creating a script for a planetarium show, one must take into account the nature of the words. In this way, planetarium scripts bridge the gap between creative writing and hard science; the script must be compelling and interesting, yet still contain enough factual evidence to be educational. I have written a script for the modern planetarium, and in doing so, I explore humanity's place in the universe by telling the story of our knowledge of planets.

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I would like to thank Dr. Ronald Kaitchuck for advising me during this long process. His advice helped me to see my thesis, not only as a scientific script, but as a creative process.

I would also like to thank my parents, Dana and Paul, for their continued support and encouragement.

Process Analysis Essay

When I first began my research for this script, I already had some idea of how it would be done. As a scriptwriter and student assistant for the Charles W Brown Planetarium, I'd worked with planetarium scripts in the past, both in editing and compiling drafts of shows that would later become some of our more accomplished works. But I had never written an entire script by myself before. In fact, most of my writing expertise lay in creative writing, in stories, or in compiling essays for class. When I started this script, I knew things would be different. I would have to pay special attention to the words.

My voice, or, my unique way of writing, differs depending on my format. When I write creatively, I try to take myself into the mind of a character, expressing emotion and thought as well as plot and scene. In an essay, I'm allowed to use flowery expressions, and I'm expected to use complete sentences and correct grammar. In a script, however, neither of these voices would be acceptable. In a script, the writer needs to pay attention to how the words sound when read aloud. In this way, run on sentences and sentence fragments are perfectly acceptable, as long as they 'sound right.' My words would need to have the right cadence, the right beat when read aloud; they would need to 'flow off the tongue' and engage the reader in a different way than I was used to. Since I hadn't had much experience in script writing, I found this aspect particularly challenging, and I often found myself writing overly complicated sentences, as if I were writing an essay. To combat this, I would speak the words to myself in my head as I wrote, and if something didn't sound right, I would change it. As I kept writing, I realized that a script is not necessarily devoid of personality or emotion. A good script evokes emotion in the listener; the right words can stir a heart, or bend an ear. Once I began allowing myself to shine through- and

stopped writing so formally-, the script improved drastically.

I also had to consider the fact that my script was never meant to stand alone. All planetarium scripts come with a description of visuals in the right side column. When writing stories, I am always expected to describe the scene, to set the stage or further the plot. In a script, most often there is no need for that type of description. The images speak for themselves. Most often, the images are actually there to help push home what the script says, or to bring an aspect of emotion into the script. A picture says a thousand words, but a picture alongside words can marry fact with speculation, and join reason with emotion. A picture can also personalize the words, and make everything seem much more realistic. It's one thing to write about the achievements of the Arecibo telescope, but it's another to hear about them while seeing the vastness of the bowl sunk deep into the Puerto Rican soil. It forms a connection between the audience and the object, a personal kind of recognition. And in order to evoke emotion in my audience, that kind of recognition can be a doorway to the heart.

When I began to structure the essay, I found it difficult to decide where to place certain information. Since the audience has a limited memory, they might not remember important facts if they were mentioned at the beginning of the show rather than in the middle. Then I realized that my script was not only a way to pass information about science to the public- I was telling humanity's story, our story of our knowledge of planets. After that, it was much easier to decide where to place ideas. Telling stories is a part of me, interwoven into my being, so it's only natural that I should find a way to express that in my script. Besides, humans as a whole love listening to stories, so making my script a story would only create intrigue and attention in my audience.

Once I had decided how to structure the script, I began to dig deeply into researching my topic: Exoplanets. I already knew a decent amount about exoplanets from my classes and my own research, so I knew exactly where to start looking for information. Since exoplanet research is such a new field, the majority of relevant information can be found online rather than in books. Even textbooks that were published only a handful of years ago are already out of date; we are continuously making new discoveries about other solar systems. While I was researching, I found myself excited, learning about all the new discoveries. Even while I was writing the thesis, new information was being discovered. In fact, the discovery of an entire solar system of worlds, the Trappist-1 system, was announced to the public while I was reworking my thesis. These discoveries reminded me of why I love science and exploration- you never know what you'll find, or when you'll find it! I did my best to channel my excitement over this topic into the script. I wrote several drafts, first on my own, and then with the help of my advisor. I prefer writing my first draft without any sort of filter, so the ideas can flow more easily. After I reviewed my own first draft, my advisor and I revised each successive draft together in order to produce a polished product. I added the descriptions of corresponding visuals, which can be found in the right hand column, after writing the first two drafts of the script. Since I didn't want my creativity limited by thoughts of what images and animations should be placed where, those were added in later, in my third draft.

Since working at the Charles W Brown Planetarium, I've had the opportunity to see firsthand how science, explained in an engaging and fun way, can make the public interested in and intrigued by science. My goal with this script is to reach out to the public and show them just how exciting astronomy can be. I want to share my love of science with others, and potentially inspire them to learn more about astronomy. In this day and age, with so many people finding

doubt and fault in logic, science is taking a back seat to opinion and speculation. People are becoming less interested in science, and more likely to turn away from it. With my script, I hope to pull the public away from their doubt and inspire them to seek the truth, no matter where it might be found. After all, science is the foundation of our understanding of the universe, and ourselves.

Beyond Our Solar System: The Search for Planets

Written by: Lilian Larson

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<p>As the Earth turns, we look up at the sky and wonder. Since humanity first walked the Earth, since we first began building fires and constructing tools, we have been looking upward, towards the stars. We watched as the sky turned around us, dots giving way to patterns, to stories, to constellations. The Sun rose in the East, and set in the West, following what seemed to be a perfectly spherical path around us. And so we imagined the sky as a great celestial sphere, and the stars as pinpricks of light spinning around us.</p>	<p>Fade in Milky Way turning from day to night.</p>
<p>But some stars did not follow this orderly path. Some of them moved in other ways, changing their position in the sky. As days turned to weeks and the seasons shifted, they moved through the sphere of stars, moving forwards, and even backwards, across the sky. Our ancestors called these traveling stars ‘planets’, or wanderers, and gave them the names of their gods.</p>	<p>Constellations forming from connected stars.</p> <p>Show planets moving, including retrograde motion.</p>

<p>Mercury, the closest planet to the sun, and therefore the fastest traveling. Venus, sometimes called the Morning Star, which goes through phases similar to Earth's moon. Mars, the red planet, named for the god of war. Jupiter, the largest planet, with its storm, the Great Red Spot, that has been swirling for centuries. And Saturn, with its prominent rings, furthest of all the visible planets.</p> <p>Our ancestors imagined these five planets orbiting around us, their positions, along with the stars, dictating the actions of their cultures and the way they lived. The sky was their compass, their clock, their calendar. And at the heart of it all, Earth.</p> <p>Then, in the year 1530, a Polish astronomer named Nicolaus Copernicus introduced a revolutionary idea to the scientific community, an idea going back to the ancient Greeks: perhaps the Sun, stars, and planets did not orbit the Earth, as was thought. Instead, he theorized that the Sun was the heart of the solar system, and that the planets, including Earth, moved around it. Copernicus' ideas were considered revolutionary, and authorities quickly dismissed the proposal. But nearly seventy years later, when Galileo</p>	<p>Show each planet as it is described, travel from space.</p> <p>Ptolemaic view of the solar system.</p> <p>Heliocentric view of the solar system.</p>
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<p>Galilei turned his telescope towards the heavens, he learned what Copernicus had said was true. In a proverbial instant, our view of the heavens, and our place in it, changed. We were no longer the center of the universe.</p> <p>As our curiosity grew, leaps and bounds in scientific progress enabled us to explore our questions about the universe. We discovered that the inner planets of the solar system were rocky, while the other planets were gaseous or icy. Uranus and Neptune, too faint to be seen by the naked eye, were discovered, bringing our total planet count to eight. Stars were not simple pinpoints of light, but massive spheres of fiery plasma, and our Sun was one of them. Through this journey of discovery, we built massive telescopes, and pushed the boundaries of human knowledge. But, although we had found answers, these discoveries only sparked more questions. Did these distant stars have planets of their own? Would alien solar systems look like ours? And, with stars as far away as they were, would we ever know they were there?</p>	<p>Show Uranus and Neptune as mentioned.</p> <p>Fiery star- active animation with solar flares</p> <p>Starting at 'massive telescopes' show: image of Yerkes, Hubble, Moon Launch animation, fade to black</p>
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<p>In 1990, Penn State professor of Astronomy and Astrophysics Alexander Wolszczan ((Wuhl-siit-zen)) was studying the radio emissions of a pulsar in the constellation Virgo. Pulsars, or spinning cores of dead stars, give off pulses of radio waves as they spin, like the spinning beam of a lighthouse. These pulses of light have a timing that is incredibly precise, so much so that they are known as the most accurate natural clocks in the universe. Wolszczan noticed that the ticks of this astronomical clock had shifted ever so slightly, on the order of milliseconds. For any other clock, this discrepancy might have gone unnoticed. But for a pulsar to have even the smallest shift in its pulses meant that something was changing the signal. Something was making the pulsar wobble.</p> <p>A planet.</p> <p>And not just one planet, but three, each about the mass of Earth and its moon.</p>	<p>Arecibo image</p> <p>Pulsar animation</p> <p>Reveal planets in simulation</p>
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<p>For the first time, we had evidence of worlds around other stars. For the first time, our solar system wasn't alone in the universe. This discovery was monumental in scope and implication: if planets existed around other stars, then perhaps planets like Earth could exist. Maybe, just maybe, life could form somewhere else in the universe.</p> <p>But were these planets like Earth? Could they be? Since pulsars give off massive amounts of deadly radiation, there was no possible way for these planets to support life. We would need to keep looking.</p>	
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<p>Astronomers turned their attention to other stars, stars like our Sun. In 1995, Swiss astronomers noticed a change in the light of the star 51-Pegasi. The star was moving in its own small orbit: a wobble. As the star moved away from Earth, its light shifted towards the red end of the spectrum in a process known as redshift. And as the star moved toward the Earth in its wobble, the spectrum shifted towards blue, in a process known as blueshift. Something was pulling the star in a tiny orbit. Humanity had found another planet.</p> <p>But this planet was different than the others we'd found. This planet orbited its star once every four</p>	<p>Redshift/blueshift animation</p>
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<p>Earth days, faster than even Mercury spins around the sun. But its size was massive, larger than even Jupiter. And it was incredibly hot, nearing 1800 degrees Fahrenheit, more than twice the temperature on the surface of Venus. Incredibly, this planet was not made of rock, but of gas. Since it was so close to its star, astronomers expected the planet to be rocky, like the inner planets of our solar system. Instead, 51-Pegasi b is a gas giant, like the outer planets of our solar system. Scientists coined the term 'Hot Jupiters' to describe these planets.</p>	<p>Show Pegasi planet orbiting- animation</p>
<p>The existence of Hot Jupiters challenged everything astronomers knew about the formation of planetary systems. If rocky planets formed near their stars, and gas giants formed further away, then how could Hot Jupiters exist? After some deliberation, scientists decided that gas giants must form far from their stars and migrate inward over millions of years, spiraling closer and closer to their Suns.</p>	<p>Animation other Hot Jupiters</p> <p>Animation- forming solar system</p>

<p>The discovery of this new planet sparked a worldwide search. Across oceans, on top of mountains, and even from space, astronomers scrambled to detect planets</p>	<p>Images Chile/Hawaii telescopes</p>
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<p>around other stars: Exoplanets. But their task was not an easy one. Even with the most powerful telescopes known to man, planets are so faint, their effects so small, that they are incredibly hard to detect.</p>	
<p>The Kepler Space Telescope was launched in 2009 with the express purpose of finding exoplanets. But it doesn't use the wobble method. Instead, Kepler measures the light coming from far away stars, and searches for a small dip in brightness.</p>	<p>Kepler animation</p>
<p>When a planet passes in front of its star, the light coming from that star dims, since the planet blocks out a fraction of the star's light. By measuring how often and how large these dips are, astronomers can determine how quickly the planet orbits its star, and how large the planet is. When Kepler first began its mission, scientists weren't sure how many planets they would find. Would planets be rare, or common? And how many of these would be like Earth?</p>	<p>Transit animation</p>
<p>Kepler opened its eye. For eight years, it watched for that telltale dip of light, surveying thousands of stars in the hope that we might find even one planet.</p>	

<p>As of February of 2017, Kepler has discovered more than two thousand exoplanets. And there are more being discovered each day. With Kepler's help, as well as telescopes on the ground, scientists worldwide have found more than three thousand exoplanets. [pause]</p> <p>Based on the number of planets found, and the number of stars surveyed, there are likely as many planets in our galaxy as there are stars. In our galaxy alone, there could be a billion or more Hot Jupiters.</p> <p>Planets are everywhere.</p> <p>What do these planets look like? We've found planets orbiting a binary pair of stars, and around tiny red dwarf stars. We've found Hot Jupiters, Ice Giants like Neptune, and Super-Earths, rocky like our home but massive. And as for Earth-like planets, Kepler's found those too. Of all the Sun-like stars in our galaxy, scientists believe that one out of five have a planet with a potential to hold life. And these Earth-like planets could be even closer to us than we expected. In August of 2016, astronomers discovered a rocky planet, with the potential for life, orbiting Proxima Centauri, the closest star to our Sun.</p>	<p>After/at pause: Show circled stars with exoplanets in Milky Way- count of planetary systems</p> <p>Show variety of exoplanets</p>
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<p>And in February of 2017, Belgian scientists discovered a solar system of rocky worlds. This system, called Trappist-1, hosts seven rocky planets, each of them about the size of Earth. But could these rocky worlds support life?</p>	<p>Trappist-1: show system in animation or image</p>
<p>Unlike Hot Jupiters, Earthlike planets would need to be rocky, with a solid surface and liquid water. If a planet is too close to its star, the water will boil, but if the planet is too far away, any water will be frozen in solid ice. In between these two extremes is the habitable zone. If we are to find Earthlike planets, potentially with life, we will find them in the habitable zones of stars, where liquid water can be found.</p>	<p>Habitable zone animation/image</p>
<p>So, what about Trappist-1? Are any one of those seven rocky planets in the habitable zone?</p>	
<p>Yes. In fact, more than one. [pause] All seven of these planets lie within the habitable zone of their star, with the potential for liquid water on their surfaces. And as for life, scientists say that three of them could be prime hosts.</p>	<p>After pause: Trappist-1 solar system image/animation</p>

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<p>But how will we know if these planets are capable of supporting life? We can't send spacecraft to these planets due to the vast distances between stars. If NASA were to send the Juno spacecraft, the fastest human-made object, to Proxima Centauri, it would take more than 17 thousand years to reach the star. And Trappist-1? 159 thousand years.</p>	<p>Juno animation approaching Jupiter</p>
<p>But there is another way to discover the potential for life. When a planet passes in front of its host star in a transit, a fraction of the star's light will pass through the atmosphere of the planet. The molecules inside the atmosphere absorb certain wavelengths of starlight. When the light reaches Earth, scientists can look at the light and see a spectrum, a record of the elements within the planet's atmosphere. By reading this characteristic 'fingerprint', scientists can tell if a planet has oxygen, carbon dioxide, and even water. Without ever going there, or seeing the planet in visible light, scientists will be able to know if the planet can support life.</p>	<p>Spectrum animation</p>

Right now, scientists can detect some of these compounds with Earth-based telescopes, but soon, a new space telescope will peer into the atmospheres of planets.	
The James Webb Space Telescope, set to launch in October of 2018, will be able to see features of exoplanets that astronomers have never been able to see before. With James Webb, we will be able to take direct infrared images of giant planets and other solar systems, and read the atmospheres of far-away worlds. With James Webb, we will be able to answer even more of our questions about planetary formation and the habitability of other worlds beyond our Sun.	James Webb animation

When we stare up at the sky, at the curve of the Milky Way galaxy, we are often struck by a sense of smallness. And yet we reach upward, driven by a desire to explore, to learn more about the world around us, our home. By reaching out beyond ourselves, beyond our solar system, we are discovering more about our own origins, and our place in this wondrous	Milky Way from Earth
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spiral of stars, and nebulae...and planets...we call home.	
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